P1.18 REMOTE SENSING OF SEMI-ARID ECOSYSTEM FUNCTION IN THE UPPER SAN PEDRO RIVER BASIN, ARIZONA

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1. **INTRODUCTION**

Ecosystem function in the semi-arid San Pedro River Basin, Arizona, is directly related to the extreme climatic conditions and the unique physiology of xerophytic and riparian vegetation. One goal of the Semi-Arid Land Surface Atmosphere (SALSA) Program was to monitor soil, plant and atmospheric conditions within the Upper San Pedro River Basin (USPB) to better understand ecosystem function and manage scarce natural resources. Integral to this goal was the use of remote sensing to measure surface characteristics at the desired temporal and spatial scales. These scales ranged from hourly measurements of single trees (suitable for handheld sensors) to monthly measurements of the entire river basin (suitable for orbiting satellites).

An interdisciplinary experiment was conducted during the 1997 growing season to investigate linkages between vegetation and hydrologic processes, and to determine relations between these processes and the spectral response of plants and soils. This report gives a short description of the field experiment and describes the approaches that will be used to derive soil, vegetation and atmospheric characteristics from remotely-sensed and ancillary data. In all cases, the reader is referred to other manuscripts in this issue for more detail on the approach, and further information about results and conclusions.

2. **FIELD EXPERIMENT**

During the 1997 growing season, measurements were made of ecosystem characteristics and processes within the Upper San Pedro River Basin (USPB) in Arizona (USA) and Mexico. In Arizona, the work was Focused on the riparian zone near Lewis Spring, which included the cottonwood/willow forest, associated grasslands and mesquite thickets. In Mexico, measurements were made at two upland sites (Zapata and Morelos) characterized by sparse native grassland vegetation. The following subsections describe the extensive set of vegetation, soil, atmospheric and spectral measurements that are being used to develop remote-sensing approaches for monitoring regional vegetation productivity and evaporation.

2.1 <u>Riparian experiment</u>

Measurements of vegetation and soil evaporation rates in a riparian zone are particularly difficult due to the extreme variations in vegetation type and density over relatively short distances. Consequently, a diverse set of equipment was deployed at the Lewis Spring site to measure the many components that make up the total water loss from the riparian zone.

Diurnal transpiration rates were measured within the cottonwood-willow riparian forest using stem heat balance and heat pulse techniques to measure sap flow (Schaeffer and Williams, this issue). These measurements were made for several days during each of four measurement periods at two sites that differed markedly in stand structure, stream flow, and groundwater depth (see overview by Williams et al., this issue).

Another set of instrumentation was deployed to measure evaporation rates of the riparian vegetation zone, including the riparian forest and grasslands, and the associated upland vegetation. A Raman lidar system was used to measure the spatial and temporal variations of water vapor around the vegetation zone (Cooper et al., this issue). Stable isotopic analysis was used to identify the water sources (precipitation, stream, soil and/or groundwater) utilized by the plant species (Snyder et al., this issue). A scintillometer was used to estimate areally averaged sensible heat flux over different vegetation types at kilometer-length scales (Chehbouni et al., this issue). Micrometeorological techniques were used to measure surface energy and water fluxes for an annual cycle over a sacaton grass and a mixed mesquite-grassland (Scott et al., this issue). These data sets will be merged with the cottonwood/willow sap flow measurements to examine the processes which govern riparian and upland vegetation evaporation rates (see overview by Hipps et al., this issue).

Soil moisture conditions were measured inside and outside the extent of the riparian forest. An intensive network of piezometers, neutron probe access tubes, water content reflectometry probes, tensiometers and stream stage recorders were installed in the river banks (Whitaker et al., this issue). In the sacaton grassland and creosote shrubland associated with the riparian forest, instantaneous soil moisture conditions were measured using gravimetric methods (5 cm depth) over large flat targets in conjunction with monthly satellite overpasses (Moran et al., this issue). At the latter sites, vegetation biomass, leaf area index, cover and height were measured monthly.

2.2 Upland experiment

Instrumentation was deployed at the Zapata and Morelos sites in Mexico to measure surface energy balance and evaporation rates. This included a meteorological tower at the Zapata site to measure diurnal energy fluxes, and a scintillomter to measure instantaneous fluxes over distances of 300, 650 and 950 m. Soil moisture was measured at both sites using Time Domain Reflectometry (TDR) sensors and Theta probes with sensitivity to 5 cm depth. Measurements of vegetation biomass, water content and leaf area index were made once a week at each location.

2.3 Associated remote sensing measurements

In support of the SALSA riparian and upland experiments, we acquired a monthly set of images from the Landsat TM and ERS-2 SAR satellite sensors (Table 1). Furthermore, at each site, measurements of surface reflectance and temperature were made with hand-held radiometers for small-scale studies and for validation of the satellite images.

At the Lewis Spring site in Arizona, five intensive measurement periods (termed SALSA synoptic runs) were scheduled for March, April, June, August and October 1997. These coincided with tree phenologic stages and environmental conditions (pre-greenup, initial leaf-out, summer drought, monsoon, and post-monsoon) and with the overpasses of the Landsat and ERS-2 satellites. In addition, arrangements were made for aircraft overpasses to provide fine-resolution (1, 5 and 15 m) images of the riparian site, the Mexican border, and several upland sites of interest. A summary of timing, coverage, and sensor specifications of SALSA-related images is presented in Table 1.

In support of each overpass, several ground-based procedures were followed to allow atmospheric and systematic correction of image data (Qi et al., 1997). These procedures included the deployment of large, calibrated reference tarps that could be easily imaged by the airborne sensors, on-site measurements of plant and soil reflectance over large areas, diurnal measurements of solar intensity for computation of atmospheric optical depth, and launches of radiosonde balloons at the time of overpass to measure atmospheric water vapor.

Table 1. List of the remote sensing information obtained during the SALSA riparian and upland experiments.

Platform	Sensor	Spectral Wavelengths	Overpass Time	Coverage
ERS-2	Synthetic Aperture Radar (SAR)	C- band (5.3 cm)	Monthly, Nov. 96 to Oct. 97, ~10:30am	~ 100 x 100 km, U.S. and Mexico sites
Landsat	Thematic Mapper (TM)	6 bands, 0.45 to 2.35 µm 1 band, 10.42 to 11.66 µm	Monthly, Nov. 96 to Oct. 97, ~10:30am	~ 180 x 180 km, U.S. and Mexico sites
DOE Cessna Citation	Daedalus - TM Simulator NASA TIMS	10 bands, 0.42 to 2.35 µm 2 bands, 8.5 to 12.5 µm 6 bands, 8.2 to 12.2 µm	Apr. 96 and Aug. 97, before 12pm	Swath width ~11 km at 15m resolution, Several U.S. sites and the Mexican border
Agro-metrics 2-engine aircraft	1-band video	8 to 12 µm	Apr., June, Aug., Oct. 97, before 12 pm	Swath width 0.25 km at 0.5m resolution, Riparian zone only
USDA-ARS Aerocommander	4-band video Large Format Camera	4 bands, 0.45 to 0.90 µm Color near-infrared film	Aug. 97, before 12 pm	Swath width ~6 km at 15m resolution, Several U.S. sites and the Mexican border

3. **RESEARCH ISSUES AND APPROACHES**

The science issues to be addressed by SALSA scientists using remotely sensed data fall into three basic categories:

1. Image processing;
2. Estimation of surface vegetation, soil and atmospheric conditions;
3. Assessment of measurement scales.

3.1 Image Processing

The images obtained in the 1997 SALSA experiment covered a broad range of spectral wavelengths and spatial scales. Images in Figure 1 illustrate an example of the diversity of information that is available from this database. Images from Landsat TM and ERS-2 SAR show the regional coverage from orbiting satellites and the differences in information content of two wavelengths (near-infrared and synthetic aperture radar (SAR)). Images from the airborne sensors show the additional information available from high-resolution airborne sensors. At the finest resolution (Agrometrics 0.6 meter thermal data), it is possible to discriminate the temperatures of individual trees and bushes.

Though visual assessment of images is interesting, the scientific objectives of the SALSA Program required that the image data be registered to UTM coordinates and converted to such physical surface properties as reflectance, temperature and radar backscatter. Furthermore, most scientists intended to use remotely sensed data in physical models which required a high degree of accuracy and precision in such measurements.

All SALSA images are being registered to UTM coordinates with 0.5 pixel accuracy in most cases. The Landsat TM images were ordered as precision/terrain corrected products from USGS and were found to be within ~0.75 pixel accuracy in both flatlands and mountainous regions. This was an improvement over the 3-6 pixel accuracy obtained in mountainous regions using manual registration without terrain correction.

The first image product produced from the SALSA data set was a high-resolution map of vegetation biomes along the USPB riparian corridor. This was constructed using unsupervised classification of several spectral bands acquired with the airborne Deadalus sensor with 5m spatial resolution (Figure 2). This map was validated with ground reconnaissance and made available to all SALSA scientists as a base map for their studies.

Several research projects have addressed the difficult issues of atmospheric correction (Watts et al.; Qi et al., this issue) and image enhancement, such as cloud screening (Yucel et al., this issue). Such basic research will allow high-quality, validated images for ongoing research projects identified in the next subsection.

3.2 Estimation of surface vegetation, soil and atmospheric characteristics

The bulk of the SALSA research is focused on the assimilation of remote sensing information into physical models to determine such surface characteristics as vegetation growth, soil moisture conditions, and plant and soil evaporation rates.

Estimation of vegetation characteristics has been achieved using several approaches. Begue et al. (this issue) inverted a canopy radiative transfer model to determine canopy structure (plant density, leaf area, and vegetation cover) from canopy reflectance measured by airborne sensors. Nouvellon et al. (this issue) developed and tested a vegetation functioning model that can utilize remotely sensed inputs to determine the seasonal dynamics of green and standing dead biomass. Chehbouni et al. (this issue) used an approach which combined directional data in the visible, near-infrared and thermal wavelengths to infer vegetation characteristics and conditions.

Surface soil moisture conditions were evaluated through integrated analysis of the SAR backscatter and the surface reflectance in the visible and near-infrared bands (Moran et al., this issue). This surface information will be useful for calibration and validation of soil moisture simulation models, which may allow spatial evaluation of soil moisture conditions with depth (Hymer et al., this issue).

Evaluation of surface evaporation rates has received the most attention by the SALSA scientists. One approach was to use remotely sensed information to drive or calibrate physical models. This approach was used with a mesoscale meteorological model (Toth et al., this issue), a basic energy balance model (Chehbouni et al., this issue), and Soil-Vegetation-Atmosphere (SVAT) models (Boulet et al.; Harlow et al., this issue). Another approach was to combine point-based measurements of evaporation rates with spatial information from remotely sensed images to extrapolate the measurements over a heterogenous region (Qi et al.; Goodrich et al., this issue).

3.3 Assessment of measurement scales

The large-area evaluation of energy balance in semi-arid topographically rough terrain is difficult because the vegetation and soil types change radically over distances of a few hundred meters. This brings to question the representativeness of point-based energy flux measurements. Studies are underway to use remotely sensed information along with ground-based flux measurements to estimate the appropriate scales for measurement of surface fluxes in hilly, heterogeneous terrain (Kerr et al.; Eichinger et al.; Schieldge et al., this issue). This information will also be useful for determining the “best” locations for micrometeorological instruments in future experiments.

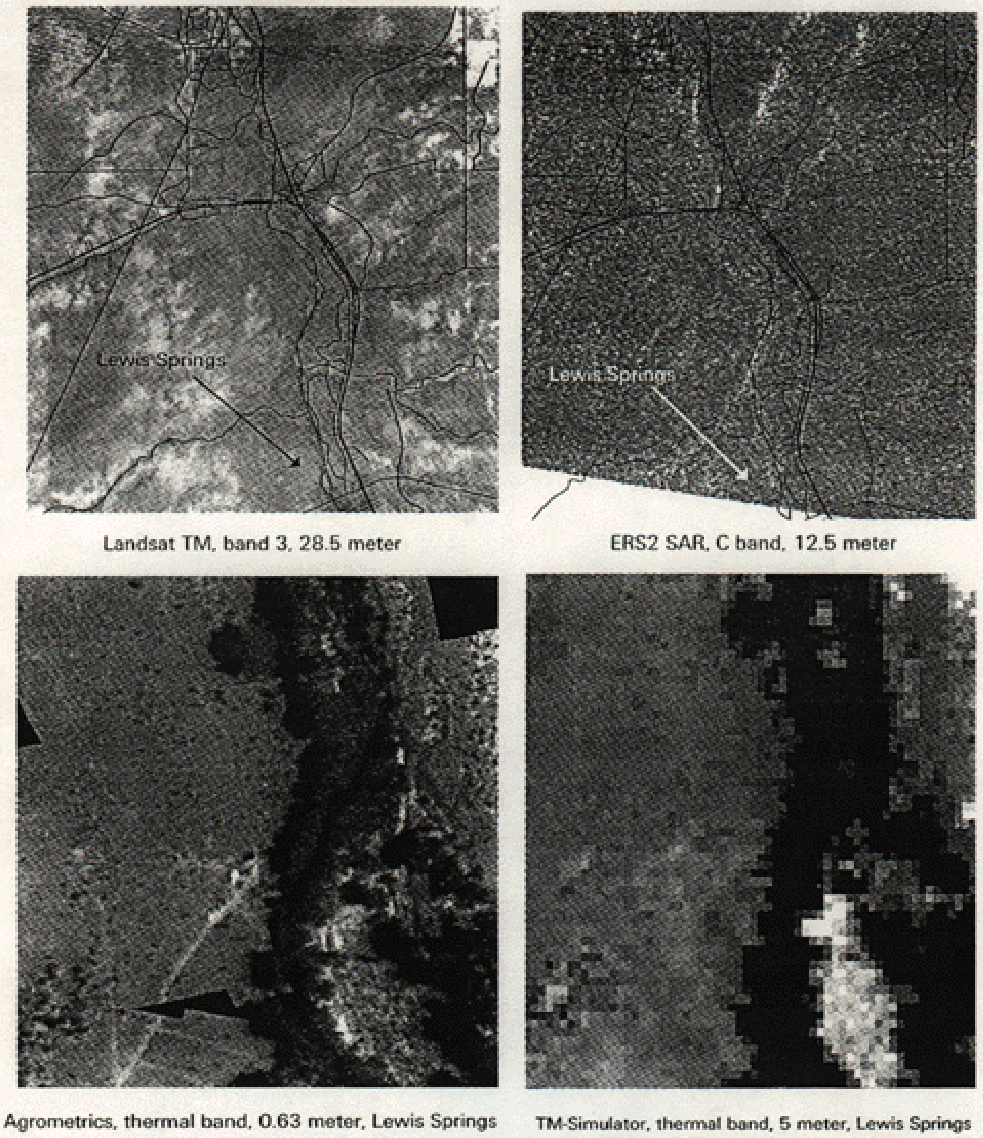

Figure 1. Examples of the spectral and spatial resolutions of images acquired during the SALSA experiment: Landsat TM (upper left), ERS-2 SAR (upper right), Agrometrics airborne thermal (lower left), and NASA JPL TM simulator thermal (lower right).

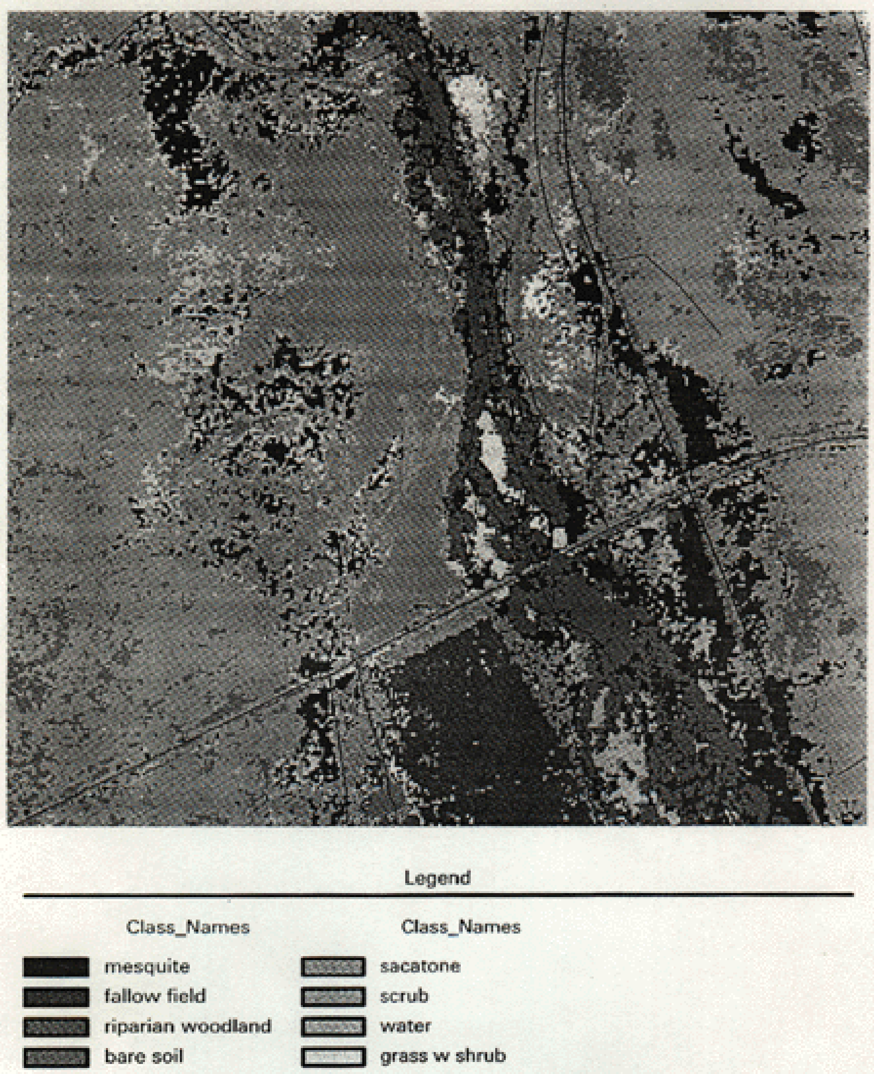

Figure 2. A high-resolution map of vegetation biomes along the USPB riparian corridor derived through unsupervised classification of several spectral bands from the JPL airborne TM simulator sensor with 5m spatial resolution.

4. **CONCLUDING REMARKS**

The interdisciplinary nature of the SALSA Program is reflected in the diversity of measurements and breadth of scientific research covered by the SALSA riparian and upland experiment. The results of this research will give a better understanding of this semiarid ecosystem function and operational means of monitoring ecosystem health through remote sensing.

5. **ACKNOWLEDGMENT**

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6. **REFERENCES IN THIS ISSUE**

Bégué, A., D. Luquet, J. Dauzat, Y. Nouvellon, and H. Rey, Vegetation hemispherical fluxes calculated from 3d computerized vegetation canopies and ray tracing technique: application to a semi-arid grassland.

Boulet, G., A. Chehbouni, and I. Braud. Mosaic versus dual source approaches for modeling the surface energy balance of a semi-arid land.

Chehbouni, A., O. Hartogensis, L. Hipps, J-P. Brunel, C. Watts, J. Rodriguez, G. Boulet, G. Dedieu, Y. Kerr, and H. De Bruin, (a) Sensible heat flux measurements using a large aperture scintillometer over heterogeneous surfaces.

Chehbouni, A., J. Qi, T. Clarke, D. Luquet, Y. Nouvellon, G. Boulet, G. Dedieu and Y. Kerr, (b) Simultaneous examination of view and sun angles effect on visible, NIR and TIR measurements over semi-arid grassland.

Chehbouni, A., R. Scott, O. Hartogensis, J-P. Lhomme, D. Goodrich, Y. Kerr, and H. De Bruin, (c) Examination of the relationship between radiative and aerodynamic surface temperature over heterogeneous surfaces.

Cooper, D.I., W. Eichinger and L. Hipps, Spatial properties of water vapor scalar and flux over a riparian corridor.

Eichinger, W.E., S. Krishnamoorthy, L. Chen, D. Cooper, and L. Hipps, The effects of surface heterogeneity on the measurement of surface fluxes.

Goodrich, D.C., J. Qi, S. Moran, R. Scott, D. Williams, S. Schaeffer, R. MacNish, T. Maddock, B. Goff, J. Toth, L. Hipps, D. Cooper, J. Schieldge, A. Chehbouni, C. Watts, J. Shuttleworth, O. Hartogensis, H. De Bruin, Y. Kerr, C. Unkrich, R. Marsett, and W. Ni, Seasonal estimates of riparian vegetation evapotranspiration using remote and in-situ measurements.

Harlow, C., J. Toth, and J. Shuttleworth Evaluation of the SIB2 surface scheme in a semi-arid region.

Hipps, L.E., D. Cooper, W. Eichinger, D. Williams, S. Schaeffer, K. Snyder, R. Scott, A. Chehbouni, C. Watts, O. Hartogensis, J-P. Lhomme, B. Monteny, J-P. Brunel, G. Boulet, J. Schieldge, H. De Bruin, J. Shuttleworth, and Y. Kerr, A summary of processes which are connected to evaporation of riparian and heterogeneous upland vegetation in arid regions.

Hymer, D.C., M.S. Moran, and T. Keefer, Monitoring temporal soil moisture variability with depth using calibrated in-situ sensors.

Kerr, Y., A. Chehbouni, L. Hipps, J. Schieldge, D. Cooper, B. Eichinger, R. Scott, D. Goodrich, J. Shuttleworth, Khil-ha Lee, C. Watts, Flux aggregation over heterogeneous surfaces in a semi-arid region: modeling and validation.

Moran, M.S., D. Hymer, J. Qi, E. Sano, R. Marsett, M. Helfert, and W. Ni, Soil moisture evaluation using synthetic aperture radar in semi-arid rangeland.

Nouvellon, Y., S. Rambal, A. Bégué, S. Moran, J-P. Lhomme, J. Qi, A. Chehbouni, D. Lo Seen, A model for grassland functioning in semi-arid regions.

Qi, J., S. Moran, D. Williams, D. Goodrich, R. Scott, A. Chehbouni, D. Cooper, L. Hipps, and W. Eichinger, R. Marsett, and W. Ni, Estimation of evapotranspiration over the San Pedro riparian area with remote and in-situ measurements.

Schaeffer, S.M. and D.G. Williams, Transpiration of desert riparian forest canopies estimated from sap flux.

Schieldge J. and A. Kahle, Use of remotely sensed and in-situ data to investigate the effects of surface heterogeneity and terrain on the spatial and temporal distribution of sensible and latent heat fluxes in the semi-arid San Pedro basin.

Scott, R., J. Shuttleworth and D. Goodrich, Water use of two dominant riparian vegetation communities in southeastern Arizona.

Snyder, K.A., D. Williams, and V. Gempko, Water source determination for cottonwood, willow and mesquite in riparian forest stands.

Toth, J.J., D.C. Goodrich, M.S. Moran, R. Scott, D. Hymer, J. Shuttleworth, I. Yucel, J. Garatuza-Payan, C. Harlow, A. Chehbouni, G. Boulet, D. Cooper, M. Kirkland, C.J. Watts, R. Avissar, R. Pinker, and L. Hipps, An overview of spatially distributed surface fluxes of heat and moisture across the semi-arid San Pedro basin

Watts, C. A. Chehbouni, Y. Kerr, O. Hartogensis, J. Rodriguez, and A. Garibay, Comparison of sensible heat flux estimates using AVHRR with scintillometer measurements over grass and mesquite in northwest Mexico.

Whitaker, M.P.L., T. Maddock, B. MacNish, D. Goodrich and B. Goff, Monitoring bank storage in the San Pedro riparian national conservation area, Arizona.

Williams, D.G., J-P. Brunel, G. Lin, S. Schaeffer, and K. Snyder, Biotic control over the functioning of desert riparian ecosystems.

Yucel, I., J. Garatuza-Payan, J. Toth, J. Shuttleworth, and R. Pinker, Cloud screened surface radiation estimates with high resolution from GOES-9 data